A study of the effects of defects in the triangle muon storage ring

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A STUDY OF THE EFFECTS OF DEFECTS IN THE TRIANGLE MUON STORAGE RING

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INTRODUCTION

A triangle geometry 20 GeV storage ring (upgradable to 50 GeV) has recently been designed, which features two decay straight sections pointing at distant detectors. The third straight section of the ring is devoted to tuning, collimation and RF.

A particularity of that design, is in its being based on solenoid focusing decay straights, which has the virtue of minimizing the betatron amplitudes, compared to equivalent quadrupole focusing. The solenoidal focusing ensures the requested ratio, for the r.m.s. divergences of the 20 GeV muon and the neutrino beam, of 0.1 for an assumed muon normalized r.m.s. emittance of 4800 π mm mr (6 π cm, total).

Details concerning this design can be found in [Ref. F. Méot, G. Rees, Report DAPNIA-06-04, CEA Saclay (2006)].

The present document reports on preliminary defect studies, and the methodology for that, based on stepwise ray-tracing.

DEFECT STUDIES : TOLERANCES, ADMITTANCE

Closed orbit defects are studied with two goals :
- assess field and alignment tolerances, and verify that they lie within regular ranges,
- assess the transverse admittance of the ring in presence of closed orbit (c.o.) defects (e.g., as resulting from uncompensated errors), and verify that it stays close to nominal value.

Stepwise ray-tracing methods are used for this study, rather than matrix and/or first order perturbative methods (which yet may be resorted to, for checking or comparisons), for the following reasons :

- the very large admittance of the ring (6π cm normalized, both planes, up to +/-3% momentum bite) requires accurate modeling of magnetic fields, including combined function dipoles (dipole to sextupole), high order multipoles, and solenoids,
- and of the ensuing large amplitude dynamics,
- and an accurate modeling of imperfections and their effects.

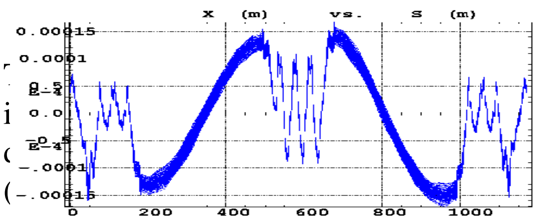


Fig. 1-a : Residual horizontal c.o., as induced by arc combined function dipoles, after correction of sextupole feed-down.

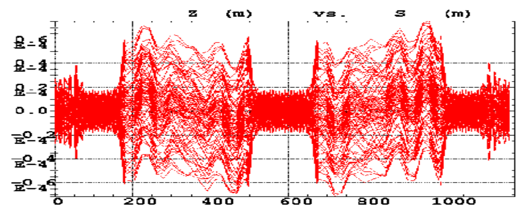


Fig. 1-b : Residual vertical c.o., induced by solenoidal coupling.

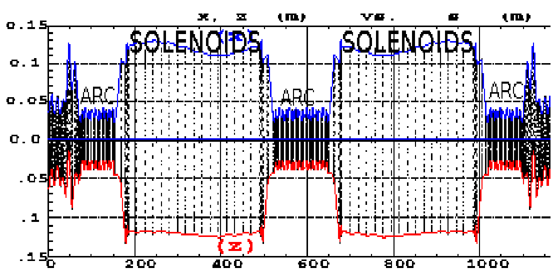


Fig. 2 : Beam tracks (from ray-tracing) and envelopes (from matrix transport) in defect free ring (blue : horizontal, red : vertical).

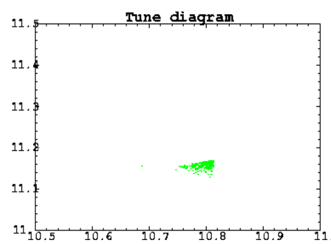


Fig. 3 : Footprint in tune diagram, chromaticity corrected, given a beam with $\varepsilon_{x,z} = 6\pi$ cm norm., $\delta p/p=\pm 4\%$.

Defect free starting conditions

The optics and admittance in the defect free ring are described in detail in Ref [1], and summarized in Fig. 1 as to the residual closed orbit, in Fig. 2 as to focusing, and Fig. 3 as to tune footprint (given corrected chromaticity, $\xi_x \approx \xi_z \approx 0$). These conditions yield $A_x=6\pi$ cm, $A_z>6\pi$ cm normalized admittances, more than ±3% momentum acceptance.

Field and alignment tolerances

For each type of defect, 100 trials are performed, corresponding to as many distributions of the error, at random (Gaussian), along the ring. This yields, on the one hand, the sensitivity to each particular defect, under the form of coefficients [x/defect_i], [z/defect_i] that connect to the rms c.o. size via

$$\sigma_{co,x}^2 = \Sigma\_i\,[x/defect\_i]\,\sigma_{\iota}^{2}, \qquad \sigma_{co,z}^2 = \Sigma\_i\,[z/defect\_i]\,\sigma_{\iota}^{2}$$

with σ_{ι}^{2} being the rms width of type "i" error distribution, and on the other hand the rms c.o. size and tune variations (due to sextupole feed-down and fringe fields), resulting from the superimposition of all defects, as shown in Fig. 4. Sensitivity coefficients for the main errors are given in Tab. 1. Note that, dipolar type of errors due to magnet misalignments and dipole field errors can be approximated by pairs of entrance/exit kicks $\theta_{i/o} = \Delta\,(Bl){=}B\rho$, with Δ (Bl) representing the effect of the imperfection ; their numerical values are also given in Tab. 1, for comparison, the correlation with tracking results is good.

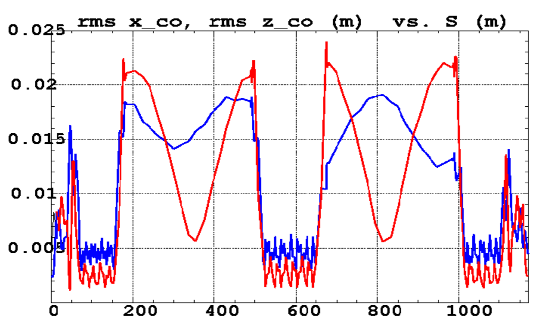


Fig. 4a : r.m.s. size of horizontal (blue) and vertical (red) closed orbits along the ring, in presence of errors amounting to three times the tolerances in Tab. 1.

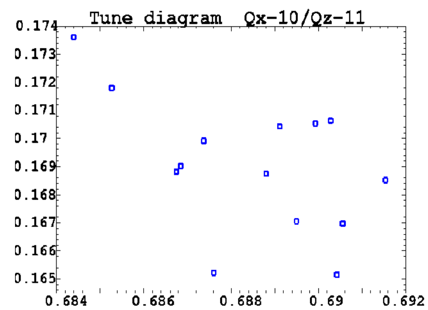


Fig. 4b : Sample paraxial tunes, corresponding to various sets of errors.

Tolerances have been estimated from the equations above and sensitivity coefficient values in Tab. 1, in the hypothesis of an r.m.s. c.o. excursion of 3.3 mm (which corresponds to 10 mm maximum c.o. excursion with 99.7% probability) ; they are given in Tab. 1. Note that 3.3 mm r.m.s. in the absence of error correction (present hypothesis) is stringent and leads to tight quadrupole positioning ($\delta\ x_{dip}$, $\delta\ x_F$, $\delta\ x_D$), this could be revisited.

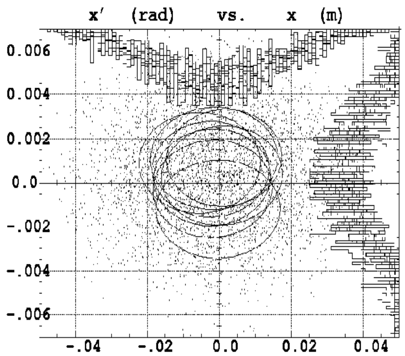
Admittance

The machine admittance has been computed in presence of the series of defect closed orbits given in Tab. 1, with rms behavior shown in Fig. 4. The method is the following.

Given a set of errors along the ring, a bunch of 10^3 particles is tracked for 100 turns. The bunch is launched with initial size is $\varepsilon_{x,z} = 6\pi$ cm norm., δ p/p in +/-3%.

Type of defect	*i/o kick value*	*Sensitivity coefficient [x/*]*	*Tolerance (rms value)*
Horizontal closed orbit			
Arc dipoles :			
$\Delta \int Bdl/\int Bdl$	-0.04	6.5 m	$4\ 10^{-4}$
$\delta\ x_{dip}$	0.22/-0.18 (F/D)	34	$0.04\ 10^{-3}$
z-rotation	-/+0.08 (F/D)	2.4 m/rad	$0.5\ 10^{-3}$ rad
Quadrupoles :			
$\delta\ x_F$	0.05	15	$0.07\ 10^{-3}$ m
$\delta\ x_D$	-0.05	10	$0.1\ 10^{-3}$ m
Vertical closed orbit			
Arc dipoles :			
$\delta\ z$	-0.18/0.22 (F/D)	17	$0.7\ 10^{-3}$ m
s-rotation	0.04	7 m/rad	$0.15\ 10^{-3}$ rad

Particles with too large amplitude are lost in the first tens of turns, so that the bunch reaches a smaller, asymptotic size, considered to reflect the machine admittance. This experience is repeated for different sets of errors. Sample results are given in Fig. 5, and show that the ring admittance does not depart strongly from $6\,\pi$ cm norm., both planes, 3% momentum acceptance.



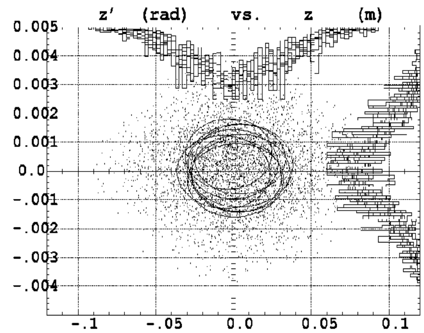


Fig. 5a : Horizontal admittance, for various sets of errors. The r.m.s. matching ellipses correspond to more than 3 π cm norm., total.

Fig. 5b : Vertical admittance, for various sets of errors. The r.m.s. matching ellipses correspond to more than 4 π cm norm., total.

Conclusions

This preliminary study shows that, (i) dipole-type field and alignment tolerances are within regular margins, (ii) in presence of strong closed orbit defects, admittances and momentum acceptance nevertheless stay close to nominal values.

So far, only closed orbit defects have been assessed, apart from focusing errors due to sextupole feed down, as stressed above. Focusing defect studies are left to further investigations.